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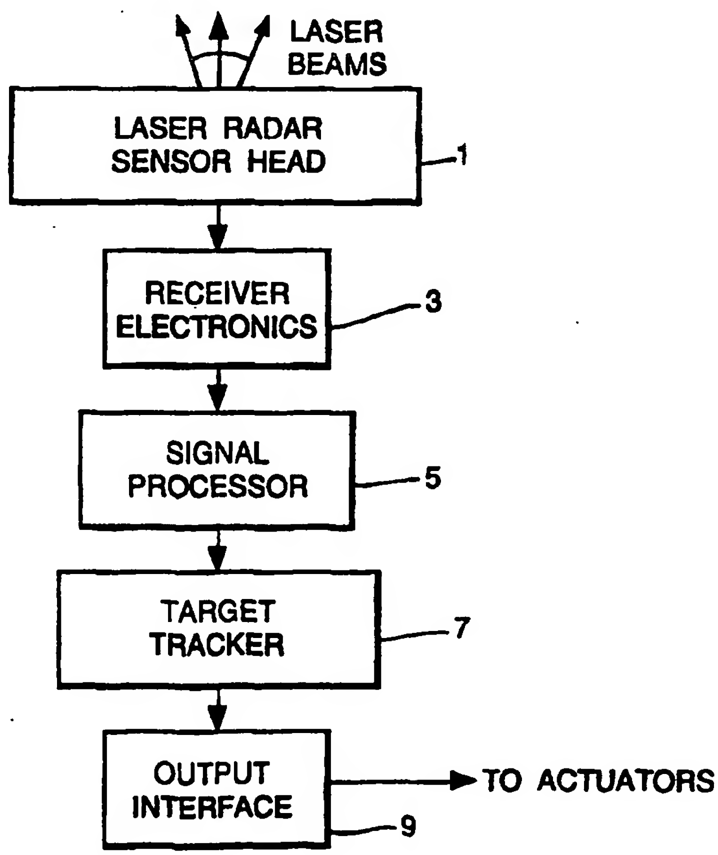
(54) Title: ROAD VEHICLE CRUISE CONTROL SYSTEM

(57) Abstract

Cruise control systems for cars enable a driver to set a desired speed and then remove his foot from the accelerator. Acceleration and braking are then undertaken automatically as hills are encountered. Further developments have been proposed involving optical and microwave measurement of distance and rate of change. No system so far completely avoids confusion by, for example, lane changing, road curving and roadside furniture. The invention provides a light-based radar system in which all targets in a field of view are tracked for a time, assessed for possible conflict and either continued to be monitored or discounted as of no interest. Target returns are stored in a digital store and correlated with vehicle dimensions by "clumping" and "erosion" of the stored signals to produce vehicle-related target clumps to be tracked.



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Road Vehicle Cruise Control System

This invention relates to a "cruise control" system for road vehicle automotive transport, e.g. cars, coaches, lorries etc.

Cruise control devices have been current on some cars for some two decades. They enable a driver to set a desired speed and then remove his foot from the accelerator pedal and relax it. Acceleration and braking, (and in more sophisticated versions, gear changing), are then undertaken automatically as hills are ascended and descended. The driver only has to steer and be mindful of catching up a vehicle in front. Safety is assured by a single touch on the brake pedal which immediately disables the system, requiring manual resetting to a different or similar speed. Such systems work well under light traffic conditions.

In recent years, refinements to the above system have been attempted by several manufacturers, to measure the relative speed and distance to the preceding vehicle and to use this information, not just to maintain a constant speed but also to maintain a safe distance to the preceding vehicle. Stadiametric, optical and microwave methods have been employed to measure the inter vehicle distance and its rate of change, but all can readily be confused by lane changing (by own or

other vehicles), road curvature, reflections, (often larger than those from the rear of other vehicles), from roadside furniture etc.

An object of the present invention is to provide a means of overcoming such problems.

According to the present invention, a cruise control system for a road vehicle includes a light-based radar system adapted to survey a region of predetermined angular extent ahead of the vehicle and to track targets within that region presenting target returns above a threshold strength, the radar system comprising means for: locating target returns in angle and range within said region; separating target returns into concentrations corresponding to road vehicle dimensions to discriminate individual targets; tracking said targets; assessing the track of each of said targets to determine whether the target presents no danger, or whether it is a potentially dangerous target requiring continued tracking; and means for producing an alarm or control output when the track of a target appears to indicate a conflict with the vehicle carrying the radar system.

The target returns are preferably registered on a 2-dimensional array of storage elements the 2 dimensions being range and azimuth angle and each of said storage elements corresponding to a range step and a linear width which are small fractions of corresponding vehicle dimensions at maximum range of interest.

Each storage element preferably corresponds to a range step less than or approximately 100 millimetres and an azimuth angle less than or approximately 1°. The array is preferably arranged to be refreshed periodically with signal samples.

The array may be duplicated for each of several elevation angle steps to accommodate variation of target elevation in uneven terrain.

The system preferably includes a signal processor which identifies groups of adjacent elements of the array registering signal samples, determines the target extent corresponding to each group and

discounts outlying elements of a group until the resulting concentration corresponds to a target dimension within a predetermined maximum value.

Such a concentration of elements may be treated by the signal processor as two sections assessed by identity of range and track and fixed azimuth separation as being left and right rear corners of a target vehicle.

The human eye-brain combination overcomes the above problems by identifying the objects of interest (e.g. other vehicles) and discriminating them from objects not of interest, such as bridges, crash barriers, roadside signs etc., by tracking each target detected individually for a period, making a decision based upon the nature of its track, on whether it is another vehicle or not, erasing it from its track store if it is decided that it is not a relevant target and maintaining track upon it if it is considered relevant.

Although the eye-brain combination cannot measure range or range rate accurately, it usually makes adequate estimates stereoscopically, kinematically or stadiametrically. It uses very high resolution images, (comprising millions of pixels), over a very wide field of view, (nearly a hemisphere) in effectively 3 colours. It has a pattern recogniton capability second to none and it can call on a huge experience store. Using this it can readily distinguish a single large veichle (say) from a closely spaced cluster of samll vehicles capable of independent trajectories. This same concept is essential to the present invention.

A cruise control system in accordance with the invention will now be described, by way of example, with reference to the accompanying drawings, of which:

Figure 1 is a block diagram of the system;

and Figure 2 is a diagram of part of a storage array employed in the system.

The system employs a light-based radar to provide narrow beams and high resolution. In this specification "light" is to be taken to mean optical wavelengths

generally, including ultra violet, visible wavelengths and infra red.

Referring to Figure 1, the system comprises a laser radar head 1 including an optical detector; receiver electronics 3 converting optical signals (radar returns) to electrical signals; a signal processor 5; a target tracker system 7; and an output interface 9 by which the system output is coupled to vehicle control actuators - brakes, accelerator, alarms.

The light transmitter comprises a solid state laser or light emitting diode driven by a modulator supplying it with very short pulses (typically 1 or 2 manoseconds), at a pulse repetition rate of the order of 5 kHz.

While a laser is an obvious source of optical frequency signals, the coherent nature of laser light is not essential to the invention. A light emitting diode providing an incoherent, high intensity, narrow beam would serve the purpose.

The radar includes a wavelength filter which predominantly passes the wavelength emitted by the laser or light emitting diode in preference to other wavelengths, arising for example from sunlight, car or street lights etc. The filtered radar returns are then subjected to focusing optics for concentrating the relatively weak echo pulses returned by detected objects on to an array of photo detectors.

The field of view is required to be basically an azimuthal arc of perhaps 45°. However, a small degree of elevation coverage is desirable to avoid the necessity of stabilising the surveillance system in elevation as the vehicle moves over road bumps, hills, etc.

The signal echoes may be gathered by an optical scanner and a single optical detector or by a staring array of optical detector elements. In either case the optical signal strength is assessed against a threshold value and transferred to an electrical storage array for processing.

Because the intensity of the echo signal returned by a detected object is strongly dependent on the range of the object, many

conventional radar systems employ a method whereby, following the transmission of each pulse, the gain of the receiver amplifier is varied from low to high in the time it takes for echoes to be returned from the shortest to the longest range required to be processed and/or displayed. Such systems are known as "sensitivity-time control" or "swept gain" systems and a similar system is employed in this invention.

Figure 2 shows a storage array storing signals from the opticaldetector system. This array comprises a series of azimuth rows each of which is loaded with echo signals from a particular range by time gating the writing process. This is done at such a rate as to obtain a range step of up to about 100 millimetres and preferably 50-75 millimetres. The azimuth angle step in this array is up to about 1° and preferably about 0°-5°. This gives an azimuth resolution of about 70 millimetres at 100 metres range.

An array of signal echoes such as shown in Figure 2 is obtained from a single azimuth scan. Where the optical detector system covers a small elevation arc, of perhaps 10° or 15°, the detector array of Figure 2 is duplicated for each azimuth row.

In the foregoing, a sensor system has been outlined with high resolution in range and azimuth in one or more elevation "cuts" or "bars" so as to be certain of intercepting all relevant vehicles ahead of own vehicle, even on bends in the road of moderate curvature.

Detections originating from the rear of most vehicles have a characteristic pattern that is mainly determined by the disposition of such highly reflecting features as rear lights, brake and reversing lights and their associated reflectors. The received echo signals are allocated to an array of range-azimuth "bins" for further processing, the value of the array element being a measure of the strength of the detection. A typical target vehicle, when scanned by the sensor will cause a number of adjacent cells of the detection array to be non-zero. A typical pattern of filled bins arising from detecting the rear of a vehicle is shown in Figure 2,

which indicates the greater number of detections from the left and right reflector clusters and relatively fewer from the central region. The signal processor is designed to exploit this characteristic pattern when it exists.

Associating detections to form plots of individual vehicles and distinguishing between several small and single large vehicle is the function of the signal processor and is accomplished by two main computationally intensive processes called erosion and clumping.

The signal processor identifies 'clumps' of detections: a clump is a connected set of non-zero cells in the detection array. Ideally, a single clump dimension corresponds to a single vehicle maximum dimension. Clumps which are larger than this predetermined clump dimension are broken down or 'concentrated' by 'erosion' into smaller, acceptable, 'concentrations'. Erosion is a process by which cells on the clump boundary are removed until the clump fragments into disconnected, smaller, clumps or reduces to an acceptable size.

The high resolution tracker receives data from each isolated clump of detections: the clump is treated as consisting of two parts, a left and a right, and for each part there are extracted the minimum and maximum range, the azimuth, and a mean signal strength.

This input data is used by the tracker automatically to initiate, maintain and delete tracks for a specified maximum number of vehicles within the sensor's field of view.

Individual vehicles have their dimension, orientation and dynamics modelled by a time varying Gaussian probability distribution. The dynamics of the left and right edges of the vehicle are coupled by the requirements that they have a common velocity and acceleration.

Vehicle detections are associated to tracks by two processes: gating and if necessary, allocation. Gating identifies those detections which have a high probability of having originated from a particular track.

Acceptable clumps are subjected to a "chi-squared, statistical test" to see which clumps have a significant probability of having originated from which tracks. More than one clump might originate from a particular target track and may tracks might appear to have been the origin of a particular clump. For each clump-track pair the gating process provides a probability of association. This probability is computed from the combined clump, track and false alarm statistics.

Following the gating process, if there exist competing tracks for a number of detections, then the detections are allocated by further computing the relevant joint association probabilities.

The final allocation is made so as to achieve the highest joint association probability.

The joint probabilities are computed from the individual association probabilities provided by the gating process. The allocation/association process allows for more than one clump to be allocated to a particular track, indeed, for short range targets, this is a common occurrence.

All target-vehicles' tracks maintain an estimate of the tracked vehicle's width. It is this tracked estimate that gives the best indication of a vehicle's width. It plays the critical role in discriminating between one vehicle and a close neighbour. The early clumping procedure only gives a first estimate of dimension.

Once associated, the detected data, (itself modelled as Gaussian probability distribution), is optimally combined with the track data using Baye's rule.

Tracks are initiated and deleted according to the output from a continuously maintained likelihood ratio test. Following each scan this test compares the a-posteriori probability that the track is due to random clutter. These probabilities make use of the probability of detecting the vehicle which is derived from the reported signal strength.

The performance of the system is considerably improved by the integration of appropriate digital map data , such as highway and lane, positional information accurate to approximately one metre.

Bends and hills on the highway, roadside furniture and target vehicle changes of lane are all possible sources of confusion for the system. These problems are substantially overcome by maintaining accurate estimates of the positions of the host vehicle and all target vehicles relative to the highway and its known lane structure.

With accurate map data the system can identify objects that are not on the highway or in the host vehicle's lane and so remove them as candidate objects to follow. Similarly a vehicle which is being followed and changes lane can be so identified.

CLAIMS

1. A cruise control system for a road vehicle, the system including a light-based radar system adapted to survey a region of predetermined angular extent ahead of the vehicle and to track targets within that region presenting target returns above a threshold strength, the radar system comprising means for: locating target returns in angle and range within said region; separating target returns into concentrations corresponding to road vehicle dimensions to discriminate individual targets; tracking said targets; assessing the track of each of said targets to determine whether the target presents no danger, or whether it is a potentially dangerous target requiring continued tracking; and means for producing an alarm or control output when the track of a target appears to indicate a conflict with the vehicle carrying the radar system.

2. A cruise control system according to Claim 1, wherein target returns are registered on a 2-dimensional array of storage elements the 2 dimensions being range and azimuth angle.

3. A cruise control system according to Claim 2, wherein each of said detector elements corresponds to a range step and a linear width which are small fractions of corresponding vehicle dimensions at maximum range of interest.

4. A cruise control system according to Claim 3, wherein each detector element corresponds to a range step less than or approximately 100 millimetres and an azimuth angle less than or approximately 1°.

5. A cruise control system according to any of Claims 2, 3 and 4, wherein said array is arranged to be refreshed periodically with signal samples.

6. A cruise control system according to Claim 5, wherein said array is duplicated for each of several elevation angle steps to accommodate variation of target elevation in uneven terrain.

7. A cruise control system according to any of Claims 2 to 6, including a signal processor which identifies groups of adjacent elements of said array registering signal samples, determines the target extent corresponding to each said group and discounts outlying elements of a group until the resulting concentration corresponds to a target dimension within a predetermined maximum value.

8. A cruise control system according to Claim 7, wherein a said concentration of elements is treated by said signal processor as two sections assessed by identity of range and track and fixed azimuth separation as being left and right rear corners of a target vehicle.

9. A cruise control system according to any preceding claim wherein said light-based radar system employs a laser light source.

10. A cruise control system according to any of Claims 1 to 8, wherein said light-based radar system employs a non-coherent highly directive light source.

11. A cruise control system according to Claim 9 or Claim 10, wherein said light source operates at a frequency outside the visible light band.

12. A cruise control system substantially as hereinbefore described with reference to the accompanying drawings.

Fig.1.

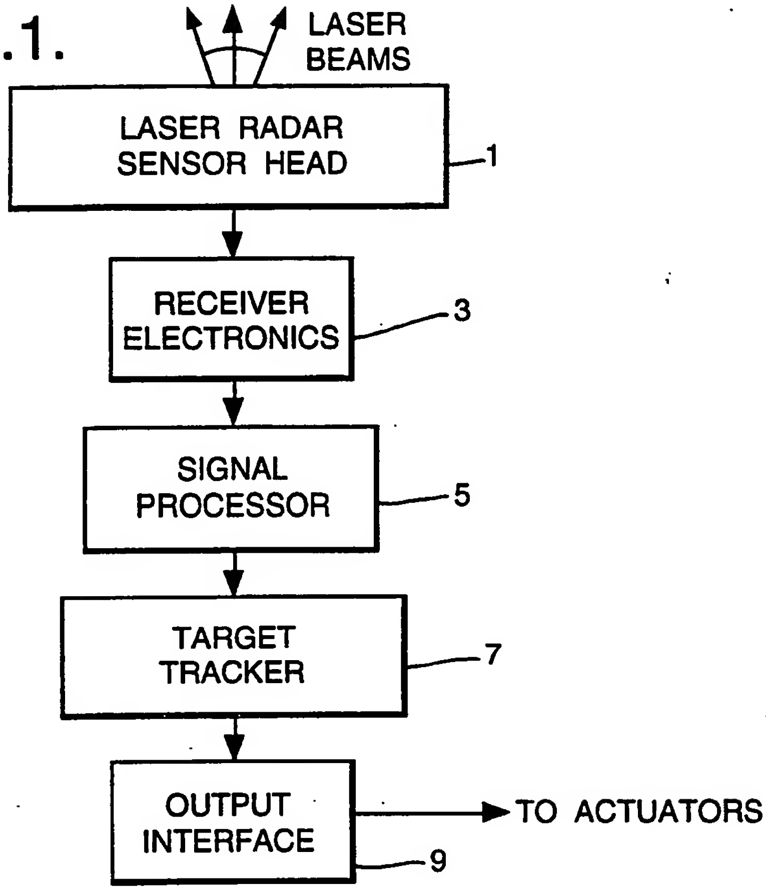
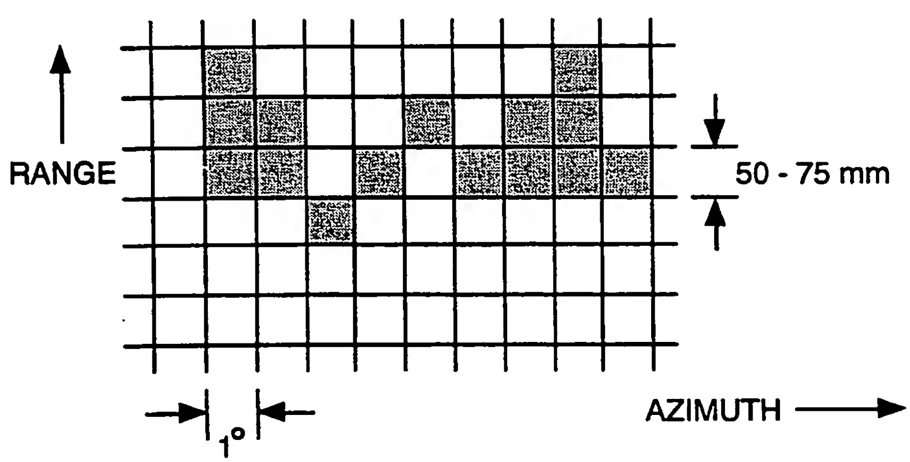


Fig.2.

PART OF THE DETECTION ARRAY (SHADING INDICATES A DETECTION)



INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 94/01379

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G01S17/93 B60K31/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G01S B60K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	EP,A,0 358 628 (TRANSITIONS RESEARCH CORP.) 14 March 1990 see column 3, line 65 - column 14, line 14; figures ---	1-6, 10-12 7-9
Y	PATTERN RECOGNITION, vol.24, no.6, 1991, ELMSFORD, NY US pages 587 - 600, XP214978 CHEN ET AL 'Object extraction from laser radar imagery' see page 588 - page 598 ---	7-9
A	DE,A,41 00 993 (MITSUBISHI) 25 July 1991 see page 4, line 2 - page 4, line 13; figures --- -/--	1-12

[X] Further documents are listed in the continuation of box C.

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	ROBOTICS AND AUTONOMOUS SYSTEMS, vol.77, no.2/3, 1 August 1991, AMSTERDAM NL pages 113 - 123, XP219094 DICKMANNS ET AL 'Relative 3D-state estimation for autonomous visual guidance of road vehicles' see the whole document -----	1-12

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Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

ormation on patent family members

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